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A highly selective dilepton trigger based on ring recognition

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Abstract

The dilepton spectrometer HADES at GSI Darmstadt investigates lepton pair production in elementary and heavy ion reactions. Since the branching ratio of these decays is on the order of 10^{-5}, a highly selective real time second level trigger (LVL2) is needed. This LVL2 consists of Image Processing Units which perform pattern recognition to detect lepton signatures in different sub detectors and a Matching Unit which combines the position and momentum information of these signatures into tracks to select events with dilepton pairs. Since the recognition of Cherenkov rings is the most selective algorithm of this LVL2, its behavior has been characterized with the help of simulations and by a comparison with the offline analysis algorithm in a dedicated experiment, which allows a better understanding of the main background sources present in the experiment.

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Keywords: RICH detector; Second-level trigger; Electron detection

1. Introduction

High Acceptance DiElectron Spectrometer (HADES) shown in Fig. 1 is a second generation magnetic spectrometer [1,2], built to identify dileptons produced in hadron and heavy ion induced reactions. The goal of this experiment is to measure the electromagnetic properties of vector mesons, as well as possible in-medium modifications of fundamental hadron properties [3]. This goal can be pursued by measuring the dilepton decay channel (e^+e^-) of vector mesons, since leptons do not undergo strong interaction in the final state. In order to select events with e^+e^- pairs of sufficient invariant mass, several detectors are needed. The momentum is measured with Mini Drift Chambers (MDC), before and after a superconducting magnet. Electron identification is performed by a Ring Image CHerenkov detector (RICH) with a hadron blind gas radiator,[3] a Time

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[3] The radiator gas C_4F_{10} was chosen for its refractive index in which leptons produced in the experiment have always the same asymptotic radius, whereas hadrons are below the Cherenkov threshold.

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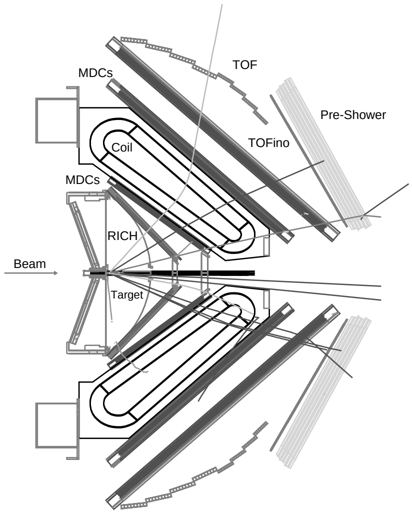

Fig. 1. Schematic view of the HADES detector cross-section. Two of the six sectors symmetrically folded, are shown.

Of Flight (TOF) wall, which can select fast particles, and a Pre-Shower detector, which can distinguish electrons from hadrons.

2. Hades and its trigger

Due to the small production cross-section and small branching ratios of the interesting decay channels (of the order of 10^{-5}–10^{-6}) a high-intensity beam has to be used to collect sufficient statistics. Thus, the approximately 100 000 channels of the HADES detector would produce an amount of raw data (3 Gbyte/s) that cannot be stored and analyzed with reasonable efforts; therefore, a fast LVL2 is needed.

The maximum data rates are generated in heavy ion reactions, when the SIS accelerator at GSI delivers a beam intensity of 10^8 Hz to this experiment. Using a thin target with 1% interaction length the resulting reaction rate is 10^6 Hz. A first level trigger based on the multiplicity of the charged particles in the TOF, indicating the centrality of the reactions, reduces the event rate by a factor 10.

The LVL2 is based on two consecutive steps: in the first step the Image Processing Units (IPUs) look for electron candidates in different detectors: Cherenkov rings in the RICH [4], fast particles in the TOF, development of electromagnetic showers in the Pre-Shower. For each of these signatures position and angle information is provided. In the second step the matching unit (MU) [5] combines the angle information from the IPUs signatures, before and after the magnetic field, to select lepton candidates, estimates the momentum of the electrons depending upon the deflection in magnetic field, and then combines electrons with positrons. Thus, it is possible to select lepton pairs with an invariant mass given by the momenta of the leptons and their opening angle.

3. Trigger performance

In order to conclusively investigate the performance of the LVL2, an external reference system would be needed: an elementary, kinematically constrained, already measured reaction, such as $pp \rightarrow pp\eta$ [6]. Without such a measurement, and with all the uncertainties of simulations given by the event generator model and the digitization, final conclusions about the efficiency of the LVL2 can not yet be drawn. Nevertheless, a comparison with the results of the offline analysis gives an important information about the relative performance of the LVL2. The main difference between the online trigger and the offline analysis is due to the different algorithms used for the ring recognition, which is also the most selective element of the LVL2.

The online ring recognition algorithm, fully described in Ref. [8], is much simpler, since it must process a full event in ~ 10 μs; the offline one [7] is much more sophisticated and makes use of additional information, since it can run without any time constraint. Although this comparison does not provide a value for the absolute efficiency of the ring recognition algorithm, it is an important indication of the relative behavior of the two algorithms, with respect to leptons and dilepton identification and signal/background ratio.

The main contribution of background dileptons present in the HADES spectrometer comes from Dalitz decays of abundantly produced π^0 and external conversion of high-energy photons in the target and in the RICH radiator gas. These pairs are characterized by small opening angles (1–15°). The currently achieved resolution of RICH (~2–3°) and inner MDC (~0.5°) does not always allow to separate the Cherenkov rings coming from such close pairs. If not properly identified and rejected, such rings increase the combinatorial background and screen the physics signal of interest.

With the standard magnetic field setting (0.5 T) used to optimize the momentum reconstruction, the low-momentum lepton from those close pairs is normally lost due to the strong deflection in the magnetic field. If such a pair is not resolved in the inner MDCs, only the high-momentum lepton is properly identified and it thus increases the combinatorial background. A dedicated experiment was therefore performed, with a reduced magnetic field (0.07 T): this set-up allows the reconstruction of non-resolved (pairs which form only one ring in RICH and one track in MDC) and semi-resolved (pairs with one ring in RICH but two tracks in MDC) close pairs, since even the low-momentum lepton can reach the outer Pre-Shower or TOF detectors (META in short). Almost the fully available statistics, of approximately 8.5 Mio C+C collisions at 1 A GeV, has been analyzed.

4. The analysis steps

The goal of this analysis is to qualitatively estimate the relative bias of the offline and online algorithms for pair reconstruction as a function of the opening angle. Due to the low photon statistics, both algorithms produce a large number of fake Cherenkov rings, not corresponding to real leptons. Since the online and the offline ring recognition algorithms do not necessarily find the same fake rings, real rings are selected by requiring a correlation between rings and lepton signatures from other detectors. This also provides a better spatial resolution and therefore the possibility to distinguish two leptons when the RICH detects only one ring.

The large suppression (almost a factor 10^3) of fake rings by requiring correlation with MDCs can be seen in Fig. 2. Here the opening angle distribution (Fig. 2) of all the pairs of rings found by the online algorithm is shown.

The structures at small opening angles are artifacts of the ring recognition algorithm: the narrow spikes result from the granularity of the RICH cathode pads. The bump near 5° is due to fake rings accompanying a real ring. These are mainly produced at a distance of approximately 1 ring-diameter from the center of the real ring. These fake rings arise from combining a couple of fired pads from a real ring with some additional noise outside of the real ring. Although a signal from real lepton pairs might be visible between 8° and 20° (dashed curve), the full spectrum is still dominated by background (fakes and random coincidence). Therefore, additional information from other detector components is needed for a further background suppression.

Fig. 3 shows the polar angle deflection in the toroidal magnetic field of these tracks correlated with a lepton signature in the outer META detector, and with a ring in the RICH. In order to disentangle the semi-resolved close pairs, which have no clear signature in the RICH, it is necessary to analyze the reconstructed tracks, which have a correlation between inner MDCs (outer MDCs are missing at the moment) and META and a small

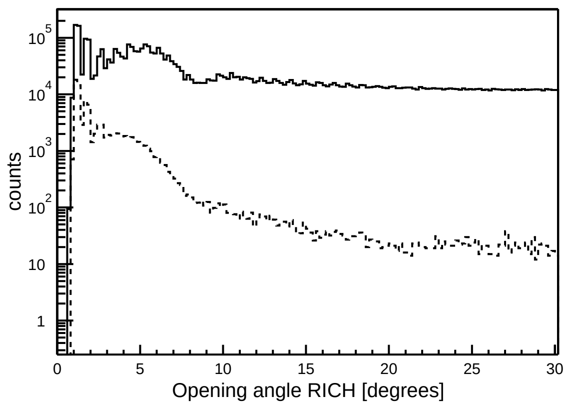

Fig. 2. Opening angle distribution of all the pairs of rings found by the online algorithm, with (solid curve) and without (dashed curve) coincidence with MDC.

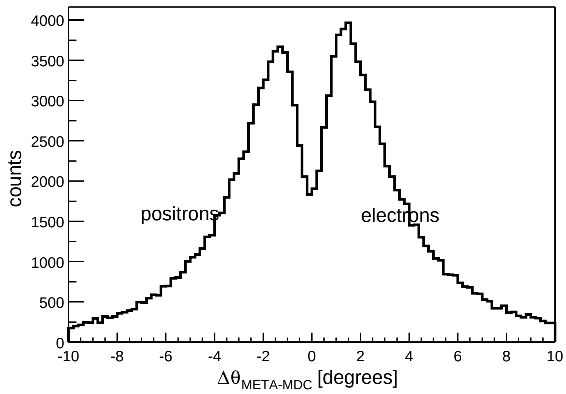

Fig. 3. Polar angle deflection of tracks correlated with META and RICH. Deflection is positive for electrons, negative for positrons. Electrons are more abundant than positrons due to HADES magnetic acceptance.

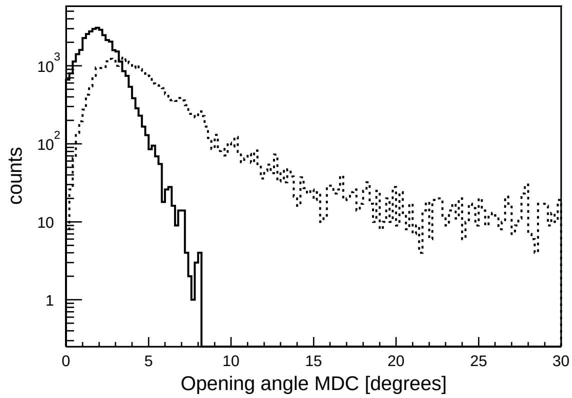

Fig. 5. Opening angle (in MDC) distribution for pairs. Rings correlated with two tracks are shown in the solid curve. Rings correlated with one track in the dashed one.

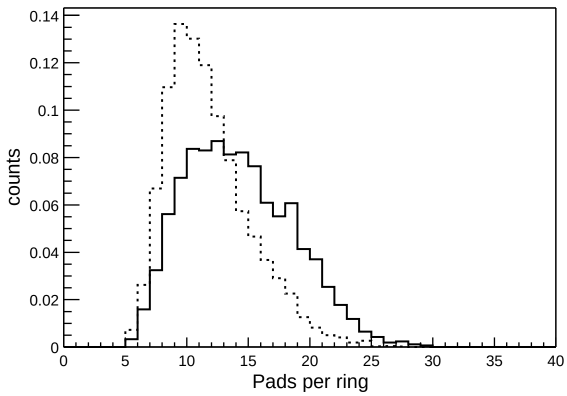

Fig. 4. Multiplicity of fired pads lying in the ring circumference. Rings correlated with two tracks are shown in the solid curve. Rings correlated with one track in the dashed one.

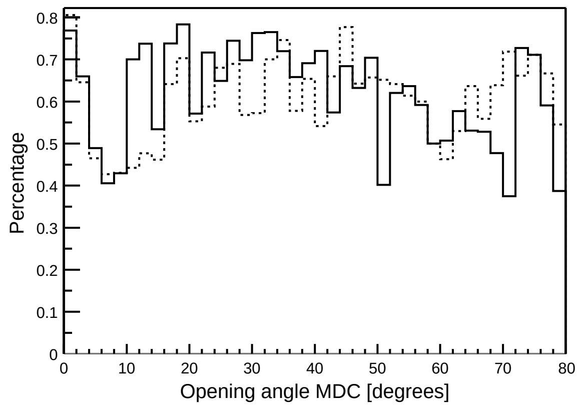

Fig. 6. Percentage of pairs found by the offline also found by the online algorithm (solid curve), percentage of pairs found by the online also found by the offline algorithm (dashed curve), as a function of the opening angle.

time of flight. Each of these tracks is correlated within a small angular window with only one ring detected in the RICH, in order to get rid of the fakes bump.

One ring correlated with two close tracks is a good indication for a semi-resolved close pair, and one ring correlated with only one track is a good indication for a member of an open pair. These two kinds of rings clearly have different characteristics, shown in Fig. 4, where the multiplicity of fired pads lying on the ring circumference, is plotted. On average rings correlated with two tracks have more pads fired. Due to the small number of pads on a ring circumference and the low granularity of the detector, there is no clear separation between the two distributions, therefore, no threshold can be established without a loss of efficiency. The opening angle distribution for these two cases is plotted in Fig. 5: tracks correlated with the same ring show a clear drop, given by the correlation window.

These pairs, correlated to the same ring or two different rings can be compared with pairs from the offline ring recognition algorithm.

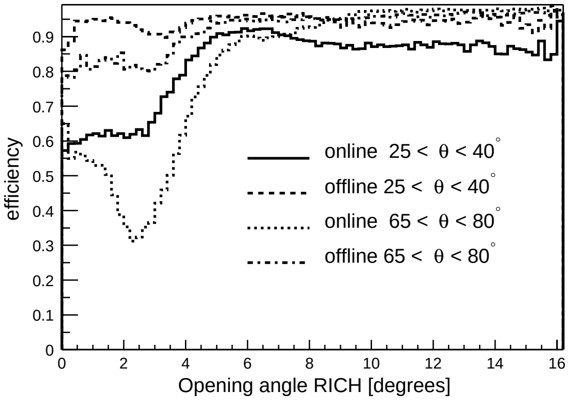

Fig. 7. Single lepton identification efficiency as a function of the opening angle for small and large polar angle, for offline and online algorithm.To keep in mind that the thresholds used by the offline algorithm are rather relaxed, whereas the ones used by the online are optimized for the reduction factor [8].

Fig. 6 shows the percentage of pairs found by the offline algorithm also found by the online algorithm and vice versa as a function of the opening angle. Both of these ratios show a drop between 0° and 10°. This loss of pairs is due to different screening mechanism for overlapping rings. It is more pronounced for the offline algorithm, which makes use of a more extended veto mask.

To investigate this problem, a set of simulations was performed: two leptons per event were emitted from the target at varying opening angles, in different regions of the detector. Fig. 7 shows the single lepton identification efficiency for the online and the offline algorithm, as a function of the opening angle. For large polar angle, the radiator length is longer, and therefore more Cherenkov photons are produced and on any average more pads fired, leading to a larger asymptotic efficiency. But in the overlapping region, a higher number of pads fired leads to a destructive interference and causes a drop of the efficiency between 2° and 4°. This effect is not present in the offline algorithm, which evaluates the ring region and the inner–outer veto region together: a ring with many pads fired in the ring region can therefore have also many pads fired in the veto region without being discarded.

5. Conclusions

The LVL2 of HADES is going into operation. Several tests have been performed in order to characterize the reduction factor achievable with different selecting conditions, but the full performance is still under investigation. With a C+C reaction at 1 A GeV, a background event reduction factor of 10 has been achieved, by requiring at least one ring detected in the RICH, and a factor between 15 and 25, depending upon the general conditions of the detector, requiring at least two rings. Correlating these rings only with TOF (half of the angular acceptance) within a large angular window, a reduction factor of 38 requiring at least one lepton, and 58 requiring at least two leptons has been measured. The ring recognition algorithm is clearly the most selective element of the LVL2. In lieu of a calibration reaction which would allow an absolute estimation of the efficiency of this algorithm, a comparison between the offline and the online ring recognition algorithm has been performed. This shows a satisfactory behavior in the identification of lepton pairs with opening angles in the interesting region ($\geqslant 20°$), although many differences in the fake production and the screening mechanism at small opening angle need to be fully understood.

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